NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum No. 33-282

VENUS: Preliminary Science Objectives and Experiments for Use in Advanced Mission Studies

(Revision No. 1)

Basic Doc (N66-27937)

Roy G. Brereton,
et al.

jpl
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

August 1, 1966

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum No. 33-282

VENUS: Preliminary Science Objectives and Experiments for Use in Advanced Mission Studies

(Revision No. 1)

Roy G. Brereton
et al.

H. J. Stewart

H. J. Stewart, Manager
Advanced Studies Office

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

August 1, 1966

Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration

FOREWORD

This document was prepared for the Future Projects Office by the author with the assistance of the following Space Science Division Scientists and Engineers:

Frank T. Barath
Walter E. Brown
Richard W. Davies
Charles E. Giffin
George L. Hobby
Alan G. Herriman
Lewis D. Kaplan
William S. McDonald
Ray L. Newburn, Jr.
Edward J. Smith
Conway W. Snyder
Robert C. Speed

PRECEDING PAGE BLANK NOT FILMED.

CONTENTS

TABLES

ABSTRACT

This document reviews current knowledge about the planet Venus and describes several scientific objectives and supporting experiments for a 1500-lb *Mariner*-type spacecraft to be flown to the planet in the early 1970's. A combination flyby/capsule mission appears to best satisfy the scientific requirements for the mission.

I. INTRODUCTION

This document describes several possible scientific objectives with their supporting experiments and also provides the scientific information for a preliminary mission study of a *Mariner*-type spacecraft to be flown to the planet Venus in the early 1970's. The study was prepared as a joint committee effort by the future projects office and the space sciences division of the Jet Propulsion Laboratory.

A launch vehicle with the capabilities of an *Atlas/Centaur* can be assumed for this mission, which means a *Mariner*-type spacecraft weighing upward from 1500 lb can be flown. A preliminary analysis indicates that perhaps three types of Venus missions are practical: (1) flyby-only , (2) added capsule-only, and (3) flyby/capsule combination.

The flyby-only mission is attractive in that (1) it is a comparatively easy mission to perform, and (2) it offers a high probability of obtaining some of the necessary Venus scientific data. However, it is to be noted that it is extremely difficult from a flyby spacecraft, to obtain unambiguous information on the temperature, pressure, density, etc. of the Cytherean atmosphere as a function of altitude, or of the hardness of the planetary surface. At the same time, the capsule-only mission omits the planetary measurements that can be made from the flyby spacecraft concerning cloud structure, surface structure, and composition of the upper atmosphere. It is also difficult to perform a capsule-only mission with the many environmental and mechanization uncertainties reducing the probability of mission success.

Of the three missions, the flyby/capsule combination is the most interesting, since it has the potential to provide the highest return in scientific information. It not only permits direct measurement of the temperature, pressure, and density of the Cytherean atmosphere as a function of altitude (and perhaps an order-of-magnitude measurement of the hardness of the surface), but it also permits radar and microwave examination of the planetary surface as well as ultraviolet and infrared examination of the upper atmosphere. These factors, together with a certain amount of redundancy of measurements between the flyby spacecraft and the capsule, make this mission very attractive scientifically.

II. THE PLANET VENUS

A. Atmosphere

Accurate physical knowledge of the planet Venus was limited strictly to the orbital elements until 1932, when Adams and Dunham obtained spectroscopic evidence of CO_2 in the atmosphere of the planet (Ref. 1). The period of rotation and axial inclination have become known only since 1962 from high-powered radar studies (Refs. 2 and 3). An accurate mass definition resulted from the *Mariner II* flight of 1962. The radius is still only poorly known due to the planet's thick clouds. In spite of the fact that Venus approaches closest to Earth of all the planets, our knowledge of it is still very limited, and it will take a rather "heroic" approach to improve the situation significantly.

Astrophysical study of Venus began with the previously mentioned discovery of CO_2 in 1932. Several attempts to determine the abundance of CO_2 followed, although it seemed likely that, due to the high opacity of the atmosphere, only a lower limit could be obtained; that is, the absolute amount above some *effective reflecting layer*. Such estimates of abundance have ranged from 20- to 2000-m atm, although recent work by Chamberlain has indicated that the higher values are probably much too high (Ref. 4). The real problems involved in reaching an accurate conclusion have been described in rather pointed detail by Chamberlain. Furthermore, accurate atmospheric structure and abundance determinations depend upon an accurate theory of spectral-line formation. The atmosphere of Venus is optically thick and full of particulate matter (clouds). Neither theory nor observations are yet in a state sufficient to provide a secure picture of the atmosphere near the cloud tops, to say nothing about the deeper atmosphere. What then do we actually know about the atmosphere of Venus?

We do know that it contains the above mentioned CO_2. Kuiper and others have identified isotopic bands due to $^{13}CO_2$ and to $^{12}C^{18}O^{16}O$, as well as the normal CO_2 with ^{12}C and ^{16}O (Ref. 5). At least some CO must be present as a dissociation product of CO_2, but the spectroscopic identification by Sinton in 1962 at 2.35 μ must be considered tentative (Ref. 6). The 1963 "confirmation" of 1.5-cm atm of CO by Moroz is a simple statement by Moroz with no presentation of observational evidence (Ref. 7).

In 1959 Strong reported the possible existence of H_2O on the planet Venus, based on balloon flight observations by Moore and Ross (Ref. 8). In 1963 Dollfus reported 100 μ of water vapor, based on observations of the 1.4-μ band from Jungfraujoch (Ref. 9). In 1964 Bottema, Plummer, and Strong flew an improved (unmanned) balloon with a spectrograph using the so-called Benedictine (multiple) slits; they confirmed the result reported in 1959 for the 1.13-μ H_2O band. They found 30 to 125 μ of H_2O, the exact amount depending upon the unknown *base level* pressure (Ref. 10). However, repeated attempts made by Spinrad to detect indications of water vapor at λ 8180, using both the existing spectra and some new spectra taken with the 120-in. reflector at the Lick Observatory, at a dispersion of 1.8 A/mm, have failed. Spinrad's absolute upper limit is 70 μ of H_2O (Ref. 11 and Footnote 1). This is a significant clue to the Venus atmospheric structure, however, for it implies a relatively high cloud level pressure, say in excess of 600 mb.

In 1963 Prokofyev and Petrova reported the discovery of O_2 on Venus from studies of the α-band at λ 6300 (Ref. 12). The observations seem marginal, although the authors claimed firm conviction. Further studies reported by Prokofyev in 1964 were little better than the earlier observations (Ref. 13). Other observations by Spinrad and Richardson dispute this discovery (Ref. 14). Observations of this type are difficult, and differences here *could* conceivably be caused by actual changes on Venus, perhaps in cloud height.

Nitrogen is also a major question. In 1954 Kozyrev reported auroral-type emission features, which he attributed to N_2 and N_2^+ in the atmosphere of Venus (Ref. 15). In 1959 Newkirk reported a partial confirmation and partial disagreement with Kozyrev's result (Ref. 16). In 1961 Weinberg and Newkirk were unable to confirm Newkirk's (or Kozyrev's) earlier work (Ref. 17). Once again, observations are difficult to make, requiring detection of a faint emission on the dark side of Venus immediately adjacent to the brilliantly reflecting lighted side at a time when the planet is relatively low on the observer's horizon. Furthermore, it is not expected that auroral-type emission will be constant in time, but rather a close function of solar activity. This is particularly true of a planet which has little or no magnetic field, as is apparently the case with Venus.

It might be expected that some argon should be found in the Venus atmosphere. There is no easy way to verify

[1]H. Spinrad, Private Communication (1965).

this from the surface of the Earth since argon has no low-excitation absorption spectrum. Other substances have been suggested from time to time as possible constituents of the Venus atmosphere. None has been identified spectroscopically.

Only CO_2 and its isotopes are absolutely accepted by all observers as being present in the atmosphere of Venus. Independent studies by Kaplan (Ref. 18), Spinrad (Ref. 19), and Chamberlain (Ref. 4) all agree that CO_2 is a relatively minor constituent of the Venus atmosphere, comprising perhaps a few percent by mass. It is usually assumed that the remainder of the atmosphere is N_2 for want of any better idea.

The brightness temperature of Venus at microwave wavelengths is quite high. Some values are given in Table 1 (Ref. 20). A number of workers have tried to explain these brightness temperatures as something other than a true surface temperature. The *Mariner II* observations of limb darkening made this task much more difficult (Refs. 21 and 22), and the 1965 paper of Clark and Kuz'min on the polarization across the disk of Venus at 10.6 cm made it virtually impossible, insisting as it does that the radiation comes from a compact surface (Ref. 23). The temperatures at 8 to 14 μ are much lower, most measurements giving about 234°K, and appear to refer to a level in the vicinity of the cloud tops (Ref. 24). Detailed studies on phase effect and limb-darkening results have been made, particularly by Sagan and Pollack, but would require considerable space for adequate exposition (Refs. 25 and 26).

The principal fact of concern is a thermal gradient of some 450°K between the clouds and surface of Venus (Ref. 20). The temperature lapse rate is at most adiabatic and possibly sub-adiabatic. This implies a very thick atmosphere and a very high surface pressure of from 5 to perhaps 100 or more atmospheres, depending upon the pressure at the cloud deck, exact atmospheric composition, etc. It also raises the question of how the elevated surface temperatures are maintained. What causes the tremendous atmospheric opacity? Pressure-broadened CO_2, CO_2 and H_2O, CO_2 plus an unknown absorber, the clouds (particulate matter), and various combinations of these have been suggested as sources of the opacity. Actually, neither theory nor observations have been adequate to deal with the problem, although at the moment, theory is perhaps in better shape than observation.

Pollack and Sagan have emphasized the urgent need for accurate limb-darkening curves at large angles to the normal, a job best attempted on a spacecraft flyby (Refs. 25 and 26). Carpenter has suggested the possibility of an accurate cloud-height determination by combining optical (laser) and microwave radar measurements from a flyby. The recent proposals for a combined optical and microwave occultation experiment should also allow cloud height determination. A laser might also allow determination of accurate albedos. Needed ground-based

Table 1. Venus microwave brightness temperatures[a]

Parameters		Reference
40 cm	400° ± >60°K	Drake (1964)
21.4 cm	528° ± 33°	Drake (1964)
21 cm	595° ± 6°	Davies (1964)
10 cm	622° ± 6°	Drake (1964)[b]
3.75 cm	616° ± 40°	Haddock and Dickel (1964)
3.15 cm	612° ± 70°	Mayer, McCullough, and Slomaker (1963)[b]
2.07 cm	500° ± 70°	McCullough and Boland (1964)
1.35 cm	520° ± 40°	Gibson and Corbett (1963)
1.18 cm	$395°\,{}^{+75°}_{-55°}$	Staelin, Barrett, and Kusse (1964)
8.6 mm	410° + 30°	Gibson (1963)
8.6 mm	375° ± 52°	Tolbert and Straiton (1964)
8.6 mm	353° ± 10°	Copeland and Tyler (1964)
8.5 mm	$380°\,{}^{+72°}_{-34°}$	Lynn, Meeks, and Sohigian (1964)
8.35 mm	395° ± 60°	Thornton and Welch (1964)
8 mm	427°	Basharinov, et al (1964)[b]
8 mm	374° ± 75°	Kuz'min and Salomonovich (1963)
4.3 mm	390° ± 120°	Kislyakov, Kuz'min, and Salomonovich (1962)
4.3 mm	$350°\,{}^{+50°}_{-30°}$	Grant, Corbett, and Gibson (1963)
4.3 mm	$330°\,{}^{+56°}_{-36°}$	Tolbert and Straiton (1964)
3.2 mm	$300°\,{}^{+57°}_{-27°}$	Tolbert and Straiton (1964)
3.2 mm	290° ± 30°	Epstein (1964)

[a]Reference 20.
[b]These are mean temperatures (at phase angle near 90 deg). All others were taken near inferior conjunction by observers who were unable to find any significant phase effect.

work includes very accurate determinations of equivalent widths, temperatures, and pressures of all accessible CO_2 vibration-rotation bands as a function of time and phase-angle at the highest possible dispersion. Additional polarization observations may also be useful, both of Venus, with telescope and from spacecraft, and in the laboratory. Probe spectroscopy in the infrared and ultraviolet regions will be necessary.

The clouds remain one of the great mysteries of Venus. Accepting Bottema, Plummer, and Strong's estimate of water vapor abundance (Ref. 10), it seems unlikely that ice clouds could form at the temperatures and pressures existing in the clouds. There are enough possibilities of error here, however, to make it unwise to discard the ice hypothesis altogether, especially since no good substitute material has been suggested in place of ice.

Suggestive observations of cusp extension at inferior conjunction and lack of coincidence of visual and geometric dichotomy on Venus have been made for years. There has been no serious published attempt to work on the *theory of scattering* in a spherical geometry, to interpret these observations. Norton is presently working on such a theory.

Scale-height information exists for the upper atmosphere of Venus (considerably above the clouds), based upon observations of the 1959 occultation of Regulus by Venus. This information is not particularly useful, however, in relation to the lower atmosphere.

Considerable information about Venus has been gained in the past decade. This information is only suggestive, however, and is not sufficient to allow one to seriously propose a delineation of *the* atmosphere of Venus. The composition is still unknown, as are atmospheric thickness and surface pressure. Until a probe can actually enter the Venus atmosphere and directly measure these quantities, the problem will be difficult to solve, but perhaps not impossible, given a combined effort of ground-based astronomy and spacecraft flybys.

B. Planetology

Our knowledge of the solid body of the planet Venus is presently limited by the cloud deck, which completely obscures the underlying surface in visual wavelengths. Telescopic and photographic observations do not reveal any sharp planetary features. Some indistinct features and occasional dark and light spots have been recorded and attributed to surface markings; however, they generally lack reproducibility in position and shape in sequential observations. Infrared photographs show no details; however, ultraviolet photographs show bands and other atmospheric markings that seem to be a normal although changing feature of the visible disk of the planet. These observations and the high visual albedo of the planet certainly suggest a dense cloud cover that permanently obscures the solid surface of Venus.

Between February and August 1964, extensive radar observations were made of Venus, employing one of the 85-ft parabolic antennas at the NASA/JPL Deep Space Instrumentation Facility (DSIF) located at Goldstone, California. Carpenter's analysis of these data indicates that Venus has a sidereal rotation period of between 243 and 254 days with the spin axis oriented within 20 deg of the orbit pole (Refs. 2 and 3). The observations further substantiate the existence of physiographic features on the planetary surface.

The observed radius of Venus is usually given as 6200 km, but the radius to the solid surface is not known because of uncertainty about the height of the layers of the atmosphere that are taken as the outer surface. Allowing 60 km for this height leads to the value 6140 km. The current value for the mass of Venus was calculated from perturbations on the orbit of *Mariner II*, and is given as 4.86954×10^{27} g. These figures give a density of approximately 5 g/cm^3, but because the true radius of the planet is not known, estimates of the density of Venus vary from 4.8 to 5.4 g/cm^3 (see Table A-1, Selected planetary data for Venus).

Measurements of the oblateness are also of dubious value. Models of internal structure are difficult to construct because so little is known about Venus' shape or moment of inertia. The rotational angular momentum is an obvious boundary condition in any origin theory. The rotation rate alone will not give the rotational angular momentum of Venus. For that, the internal distribution of material is needed. Since Venus is similar to the Earth in both mass and radius, it might be expected that the planet consists of three main zones like the Earth—a liquid core, a solid mantle, and an outer crust. Thus, assuming Venus is not extremely anomalous in its mass distribution, the rotation rate does give an order-of-magnitude estimate of the angular momentum.

The similarity of mass and density of Venus and the Earth suggests that the two planets have had broadly similar evolutions. By analogy with the probable density distribution of the Earth, Venus contains a core whose radius approximates half the radius of the planet. This inference is supported by Urey's calculation (Ref. 27) that Venus contains about 45% iron–nickel phase (by weight under zero pressure), based on the assumptions that the mean density of the planet (ρ = 4.8 g/cm^3) is produced by silicates (ρ = 3.3 g/cm^3) and metal phase (ρ = 7.2 g/cm^3). Lyttleton (Ref. 28), based on a two-zone model and several boundary conditions which he carefully discusses, gives the core-mass for Venus as 1.0×10^{27} g, or just over one-fifth of the mass of the planet, as compared to one-third for the Earth's core.

The internal thermal regime of Venus is obviously unknown, but if a surface temperature of 600°K has existed on the planet for some length of time, the flux of heat from the interior has been affected in an important way. MacDonald (Ref. 29) has calculated that temperature at a depth of 200 km in Venus is about 200°C higher than at the same depth in the Earth, assuming Venus to have a chondritic abundance of the radioactive elements. The temperature should exceed the melting point of silicates at this depth, and magmas may be formed to a greater degree in Venus than on the Earth.

The probability of melting in Venus suggests that volcanism has occurred and that constructive land forms have been so produced. The complexity of a Venusian crust is probably a function of the kinds and intensities of erosive and depositional mechanisms operative. If liquid water is currently absent from the surface of Venus, the present relief would be a function of the rate of wind erosion vs rates of crustal deformation and volcanism. If the atmospheric circulation is very great, the planetary surface might approach a vast plain overlain by a dust-filled atmosphere.

It should be emphasized, however, that current conditions on the surface of Venus may be vastly different from conditions in the past. Urey (Ref. 27), as early as 1952, first pointed out that H_2O is by far the most cosmically abundant oxidizing agent and that much water necessarily must have existed on Venus in the past in order to provide sufficient oxygen for CO_2. Photodissociation of H_2O, oxidation of carbonaceous molecules, and escape of hydrogen were the probable events in the depletion of Venus' water. The more rapid depletion of water from Venus than from the Earth may have been due to its closer proximity to the Sun. Urey (Ref. 27) further suggested that increasing CO_2 pressure was buffered in the presence of water by the reaction:

$$CO_2 + \text{Ca, Mg silicates} \longrightarrow \text{carbonates} + SiO_2$$

At room temperatures, the Gibbs free-energy is negative at CO_2 pressures exceeding 10^{-5} atm. It is thus postulated that great quantities of carbonate rocks were formed on Venus until insufficient water remained on the planet as a reaction medium. At high temperatures, the reaction is reversed, and Urey supposed that the limestones were decomposed by plutonic activity to restore CO_2 to the atmosphere. Although specific events in this sequence are obviously somewhat obscure, it emphasizes the point that Venus has probably evolved through a wide spectrum of conditions.

If the illuminated side of Venus has a temperature of around 750°K and surface water pressure is negligible, surface conditions are truly in the metamorphic realm. Surface phase assemblages formed in the past may have been transformed to new assemblages which are stable under the existing environment. In general, many hydrous phases would either have partly dehydrated or have converted to new anhydrous phases at 750°K, zero water pressure, and 50 atm of total pressure. For instance, prominent hydrates on Earth such as brucite, kaolinite, chrysotile, gibbsite, and goethite may not occur on the illuminated surface of Venus.

From the foregoing section, it is fairly obvious that we must acquire some very fundamental facts about Venus before we can proceed with a complicated scientific investigation. The initial step is to develop a model of Venus as it is today. We first need to determine the surface temperature and its variations with time and location, the atmospheric pressure and atmospheric composition at the surface, the rotational period of the planet and its axial orientation, wind conditions on the planet, and, of most importance, the amount of relief on the Venusian surface. These facts would allow us to understand the surface as it is today and the modifications that it undergoes under the existing environment.

Furthermore, gross body parameters of Venus must be measured so that the present configuration and internal structure of the planet can be understood. Measurements of mass, radii, and moments of inertia are needed. Measurements of the surface heat flux are necessary for evaluation of the existing internal thermal regime of Venus. The strength of any magnetic field of Venus, together with knowledge of the size of the planet's core, may further the understanding of the origin of the Earth's magnetic field.

The principal problem of Venus, however, is the change that has been occurring on the surface during the history of the planet. The details of that history are probably well recorded in the stratigraphy of the surface layers of Venus, and examination of stratified rocks on the surface of the planet should take major emphasis in subsequent lander and orbiter missions. From detailed visual, textural, and mineralogical studies of the Cytherean rocks, combined with relative and absolute age determinations, the geological history of the planet may be reconstructed. It may be possible to ascertain if oceans existed on the planet, the time at which existing conditions started, the degree of internal melting, the erosive mechanisms of the past, and the existence of life in the past. These investigations must consider the probable transformations that the rocks may have undergone in the existing surface temperature–pressure environment and tectonic activity. Visual reconnaissance on a large scale is necessary in order to show the existence of fold belts, which will suggest the past thermal regime. The delineation of the geological history of Venus is especially important when it is considered that the evolutionary course of Venus and that of the Earth might be somewhat parallel because of observed similarities in mass and in bulk composition.

C. Biology

The exploration of Venus has significant potential interest to biology. Although the results of microwave observations indicate that the surface temperatures are higher than 600°K, these results are not yet conclusive. Disagreement still exists about the surface temperature. If the temperature is above 600°K, the probable existence of conceivable life on the planet is extremely unlikely. However, the interests of biology are not limited only to the search for life on Venus.

Assuming that life cannot exist on the planet, information about Venus' organic chemistry is important. The problem of the origin of life is closely related, by present theories, to the organic chemical evolution of the planets. Both the present state of organic chemistry on Venus, as well as information about possible past states (as might be determined by subsurface exploration), may contribute to further development of these theories. Evidence of any thermal and other conditions on Venus favorable to the origin and evolution of life in the past might still be preserved beneath the surface in the form of organic chemical residues.

Finally, the range of conditions under which biogenesis may occur and the ultimate potential of biological evolution, are questions that cannot yet be answered with certainty. Therefore, it is presently premature to presuppose that Venus is not biologically interesting.

Preliminary information that might increase or decrease interest in the planet for biological studies is:

1. Further verification of the surface temperature.
2. Spatial distribution of the surface temperature.
3. Temperature profiles of the atmosphere.
4. Detailed composition of the atmosphere, including trace constituents and volatile organic compounds.
5. Existence or absence of organic matter, either on or beneath the surface.
6. Temperature profiles of the subsurface.
7. Characteristics of organic matter, if it exists.

D. Fields and Particles

Monitoring of the interplanetary medium with plasma probes, magnetometers, and solar proton detectors during the interplanetary cruise phase of a Venus flyby mission is of interest because of the rarely available opportunity that it affords to discriminate between temporal variations and spatial variations in the medium by means of widely separated—more or less—simultaneous measurements. The extent and shape of plasma clouds or shocks produced by solar flares, and of long-lived plasma streams such as were observed by *Mariner II*, can probably be determined in no other way. Venus-bound spacecraft are particularly appropriate for such studies because the spacecraft is close to the same solar magnetic field line as the Earth for a considerable part of the flight.

Because of the inherent nature of the plasma physics, the study of the charged particles that make up the interplanetary plasma proper, and the study of the magnetic fields that are associated with it, are really inseparable parts of the same problem. The two main goals are in the investigation of the physical processes in the solar corona and of the basic plasma physics of the interplanetary medium. For the former, we shall wish to measure the intensity, extent, chemical composition, and temporal variations of solar-plasma streams, and to identify their sources. Measurements over a wide range of heliocentric latitudes and longitudes will eventually be required. For the latter, we shall look for interactions of the plasma with magnetic fields (both planetary and interplanetary), with solid bodies, with comet tails, and with other clouds of plasma. Wave motion and plasma instabilities will also be of interest. The position and nature of the transitions between "supersonic" and "subsonic" flow in the solar wind, and the phenomena occurring at the boundary between the solar and galactic fields, should be investigated. Other questions associated with the physics of the plasmas are the source of the Van Allen belt particles, the nature of the mechanism of their injection into the magnetosphere, and the detailed nature of geomagnetic disturbances.

The nature of interaction between the planet Venus and the solar plasma was left completely undetermined by the *Mariner II* flyby, but it could be investigated by a spacecraft that passes considerably closer to the planet or penetrates the conical region where the Sun-planet-probe angle is greater than about 140 deg. If the magnetic moment of Venus is as high as 1% of the Earth's, or roughly an order of magnitude less than the upper limit inferred from the *Mariner II* results, we would still expect to see a bow shock and a transition region in the plasma similar to that around the Earth's magnetosphere. If the moment is still an order of magnitude smaller, the incoming solar wind may be simply absorbed by the atmosphere, producing no shock and no transition region, but only a narrow cylindrical cavity in the plasma behind the planet. So many unexplained phenomena have been observed in our own magnetosphere that attempts to predict the nature of the Venus-plasma interaction are probably futile.

If the solar wind is able to make a direct encounter with the upper atmosphere of the planet, then auroral emissions will be produced, either uniformly over most of the sunlit hemisphere if the magnetic field is truly negligible, or in localized regions if it is not. A knowledge of the incident solar-wind flux and energy, obtained from a plasma spectrometer, would assist in the interpretation of spectral measurements of these emissions, which might be detectable either in the ultraviolet or radio-frequency regions.

It is well known that the *Mariner II* trapped radiation experiment gave a negative result. For this reason, as brought out in the above discussion of planetary plasmas, any trapped radiation experiment would require either that the spacecraft pass much closer to Venus than did *Mariner II* (41,000 km from the planet's center) or at least penetrate the region where the Sun-planet-probe angle is greater than 140 deg. Obviously, the correlation of the trapped particle data with the magnetometer and plasma data would be of great interest. The instrumentation for the trapped radiation experiment would also give valuable data during interplanetary cruise.

The scientific objectives involved in repeating the measurements of magnetic fields near Venus would be the same as for *Mariner II*. Important questions concerning the interior, the upper atmosphere, and the charged particle environment of Venus concern the strength of the magnetic field. Direct measurement of the magnitude, multipole order, and orientation of an intrinsic field could have an important bearing on the validity of the dynamo theory of planetary magnetism and the related question of whether or not Venus has a molten core. The spatial extent and temperature of the upper atmosphere depends, in part, on the ability of a planetary field to divert the solar wind. A planetary magnetic field governs the trapping of high-energy charged particles and the extent to which cosmic and solar radiation can penetrate to the surface.

To do a significantly better job than *Mariner II*, the spacecraft ought to approach a significantly closer distance to Venus. The shock front associated with a magnetic dipole moment only 10^{-3} times the Earth's would probably be detectable at an aphrodiocentric distance of $\sim$15,000 km. If the dipole moment is really that small, the magnetic measurements would have to be performed at about one-half the above distance (or $\sim$1,000 km above the surface) for a good chance of being representative of the intrinsic field. Penetration distances even closer would enhance the chances of detecting the planetary field, or alternatively, would serve to lower the bound on the planetary magnetic moment. However, if the dipole moment is much smaller than $10^{-3}\ M_E$, any field attributable to Venus might be caused by the diffusion of interplanetary magnetic fields into the planet rather than by electric currents in a molten core. This could introduce an element of ambiguity into the interpretation of the results, but it would be of interest to know into which category the magnetic field of Venus belongs.

If as suggested Venus has a very small intrinsic magnetic moment, or none at all, the solar wind will carry its imbedded magnetic field down to the point in the atmosphere of Venus where either the pressure of the ionized components of the atmosphere or the viscosity through the nonionized components provides enough momentum transfer to stop further penetration of the solar wind into the atmosphere. Outside this region, there will be a typical bow shock, except that its shape will be that surrounding a spherical obstacle rather than a blunt-nosed magnetospheric shape. Presumably, the bow shock would occur somewhere in the general range of 1.15- to 1.3-planetary radii, depending on the Mach number and the nature of the subsonic flow between the shock front and the atmosphere. Thus, a very close passage by Venus would be desirable. It would also be desirable to explore both the tail and the subsolar region.

Although many features of the magnetic environment of Venus could be investigated even if the spacecraft field produced an uncertainty in the measurement of 2 to 5 gamma, this much uncertainty would make it very difficult to determine the true nature of the shock. For such investigations, the spacecraft field should be known to at least 0.5 gamma and it would be highly desirable to aim for 0.2 gamma.

III. PRELIMINARY SCIENCE OBJECTIVES AND EXPERIMENTS

A. *Objectives*

The two principal objectives of planetary science are the understanding of (1) the origin and evolution of life, and (2) the origin and evolution of the solar system. In spite of the alleged high surface temperatures, Venus is still interesting from the point of view of biology and the origin and evolution of life. This is because of some uncertainty regarding the interpretation of the radio emission from the planet, the possibility of elevated topography, especially at high latitudes, having lower temperatures, and the possibility that aerial life forms have evolved suspended in the cooler portions of the atmosphere. Moreover, Venus is similar to Earth in mass, size, and density; therefore, it possibly has a core and its surface is shaped by the same construction forces that act upon the Earth. Venus has a dense, meteorologically interesting atmosphere, and its study may yield important clues toward understanding the origin and evolution of planetary atmospheres. The study of Venus, thus, can be very important for a better understanding of terrestrial problems, as well as providing information useful for a solution of the two principal objectives of planetary science.

In this section, several specified scientific objectives and the resulting scientific experiments or instruments to satisfy these objectives, are presented. This section should provide the preliminary information for the numerous trade-off studies involving the scientific instruments and their weight, power, and data rate, with spacecraft design, DSIF, trajectory, and other considerations. Section B and Table A-2 present typical flyby science; Section C and Table A-3 present typical capsule science.

B. *Flyby Science*

Scientific investigations to be conducted from the flyby spacecraft involve both planetary and interplanetary experiments. The planetary experiments involve the measurement of select portions of the electromagnetic spectrum, ranging from the vacuum ultraviolet and far infrared to microwave and radar frequencies. The instruments can vary from reasonably heavy, complicated, high-data-rate spectrometers, interferometers, image-forming and scanning devices, to relatively simple, lightweight radiometers and photometers. They all have narrow fields of view and exacting, pointing and aiming requirements relative to the planet. It is possible that several instruments could be mounted on a common scan platform to provide the gross aiming capability. A Venus flyby miss-distance of 1000 km is desirable for these experiments; however, a miss-distance of up to 5000 km would be satisfactory.

The interplanetary experiments involve the measurement of planetary magnetic fields and trapped radiations as well as the interplanetary measurements. The several experiments considered here in this category have either been flown before or their application to this mission involves a relatively straightforward extension of instrument state-of-the-art.

In the following pages, several select Venus flyby scientific objectives and the resulting experiments are presented. The list is not complete; however, it is considered typical and appropriate for providing the detail of required information for a preliminary mission study. From the science point of view, it would be desirable to fly all of these experiments and others, especially since the data from one experiment will tend to supplement another, but this involves a formidable payload weighing about 200 lb, not including the data automation system or scan platform. Obviously, some selection is required to designate a so-called minimum payload for mission analysis. It is not within the mechanism of this document to completely debate the absolute scientific merit of any particular experiment over another; however, in the judgment of the committee preparing this document, a typical minimum payload for mission analysis is comprised of the first eight experiments discussed in the text and listed in Table A-2. This group includes the combination microwave experiment, the infrared experiment, magnetometer, trapped radiation, solar plasma, cosmic dust, RF occultation, and an ionization chamber/particle flux detector.

1. Microwave Experiment

Venus is of extreme interest in the microwave region since its optically thick cloud seems to be penetrable only by microwaves. Active microwave (radar) observations are suited for surface reflectivity measurements and surface imaging; passive (radiometric) observations are ideal for the study of surface emissivity and surface thermal mapping, as well as atmospheric characteristics.

In the passive microwave area, the following specific scientific objectives for spacecraft experiments can be listed for a lightweight flyby mission:

a. Atmosphere brightness temperature distribution. The limb-to-limb brightness temperature distribution of the Venusian atmosphere could be obtained at several wave lengths in the region of 3 mm to 3 cm. From Earth-based measurements, it has been well established that the brightness temperature integrated over the disk of the planet varies from about 350°K at 3 mm to about 575°K at 3 cm. The transition curve is irregular, appears to include emission lines, seems to fluctuate as a function of time, and in general, is thought to result entirely from the complex atmosphere of Venus. The shorter wavelengths are thought to originate from the top of the atmosphere, the longer ones from successively deeper layers. By obtaining limb-to-limb brightness temperature scans over a large portion of the planet at the high resolution obtainable from a spacecraft, information such as limb darkening, geographical distribution, phase angle effects, polarization, and Brewster angle phenomena could be measured. Data of this kind are extremely difficult, if not impossible, to gather from Earth because of the limited angular resolution of radio antennas. The information would yield considerable detail about the composition, the three-dimensional physical and thermal structure, the circulation, density, etc., of the atmosphere.

b. Thermal map of the Venusian surface. A thermal map or image, made at a wavelength longer than 3 cm to ensure penetration to the surface, would permit isolation of surface features such as mountains, plains, continents. It would identify thermal abnormalities such as fault lines, and volcanoes, and would yield estimates of gross surface composition and structure.

Both of the above scientific objectives are best met if the flyby distance is in the order of 1000 km from the surface of the planet. At this distance, the areal resolution of instruments suitable for a light spacecraft would be in the order of kilometers to tens of kilometers, depending on wavelength. The closer one passes to the surface, the higher the resolution but the poorer the coverage; farther out, the inverse situation is true, up to a point. Useful information, however, could be obtained as far as 100,000 km from Venus. A final flyby distance specification needs further study.

c. Implementation.

1. *Multifrequency instrument for atmosphere study.*

Wavelength: 2 to 4 wavelengths between 3 cm and 3 mm

Weight: 35 lb

Volume: 3 ft × 3 ft × 2 in. square antenna = 1.5 ft³
2 ft × 1 ft × 9 in. electronics = 1.5 ft³
Total...... 3.0 ft³

Power: cruise: none
encounter: 30 w average

Data rate: 30 bits/sec, approximately

Other requirements: planetary sensing/scan platform to scan whole radiometer at 1 deg/sec from limb to limb and 5 deg beyond each limb. Pointing accuracy not critical (±1 deg).

2. *Surface imager.*

Wavelength: 3 or 4 cm

Weight: 25 lb

Volume: 3 ft × 3 ft × 2 in. square antenna = 1.5 ft^3
1 ft × 1 ft × 9 in. electronics = 0.8 ft^3
Total ...... 2.3 ft^3

Power: cruise: none
encounter: 10 w average

Data rate: 30 bits/sec, approximately

Other requirements: planetary sensor to orient antenna along local vertical; required pointing accuracy (±1 deg); instrument scans electronically.

3. *Combined atmospheric sensor and surface imager.*

Wavelength: multiple between 3 mm and 3 cm

Weight: 50 lb

Volume: 3 ft × 3 ft × 3 in. square antenna = 2.5 ft^3
2 ft × 2 ft × 9 in. electronics = 3.0 ft^3
Total ...... 5.5 ft^3

Power: cruise: none
encounter: 40 w average

Data rate: 60 bits/sec, approximately

Other requirements: planet sensor/scan platform to scan whole instrument at about 4 deg/sec

2. Infrared Experiment

The maximum information about the cythereagraphical distribution of atmospheric composition, vertical temperature structure, and the nature and height of the clouds can probably be obtained from measurement of the spectrum from 1.2 to 5 μ, with a spectral resolution of 0.5 cm^{-1}, if we restrict ourselves to techniques within the state-of-the-art. In fact, such a requirement almost specifies a Michelson interferometer such as that now being developed at JPL for a Mars 1973 *Voyager* mission.

A resolution of 0.5 cm^{-1} would be necessary and sufficient to measure absorption of solar radiation at the center and wings of lines in the high-frequency CO_2 bands, from which CO_2 amount and cloud height can be determined, and in the 4.3-μ CO_2 band, from which high-resolution vertical temperature structure can be determined. This resolution should be more than sufficient to provide cloud temperatures from measurements near 4 μ. The spectral resolution would also be necessary to identify and measure some of the gases likely to be present above and in the clouds, and sufficient for most. If the clouds are mostly the condensation products of atmospheric gases, as is likely, these could be detected and measured with sufficient accuracy to identify them and determine whether their composition is consistent with the cloud temperatures. For example, if the clouds are composed of organic compounds, these will show up very clearly in the 3- to 3.5-μ region, and probably from 2 to 2.5 μ. Likewise, it would be possible to determine from measurements in the H_2O bands whether the cloud tops could be expected to contain ice crystals. More direct evidence for the cloud composition should come from the continuum spectra of the clouds themselves. Breaks in the clouds could also be detected if there are atmospheric windows between 3 and 4 μ.

The information from this experiment should be a great help in planning future capsule missions. Even if a simultaneous capsule mission is planned, there is a possibility that it will fail because of incompatibility with the environment. Thus, at the least, the flyby measurements would probably indicate the cause of the incompatibility.

The data requirement for 0.5 cm^{-1} resolution from 1.2 to 5 μ at 1% accuracy will be about 300,000 to 400,000 bits per interferogram, or about 10^3 bits/sec if data are sent in real time. The instrument would weigh about 35 lb.

3. Magnetometer

The scientific objectives involved in repeating the measurements of magnetic fields near Venus would parallel those for *Mariner II*. However, to notably improve upon *Mariner II* data, the spacecraft ought to approach significantly closer to Venus. The shock front associated with a magnetic dipole moment only 10^{-3} times the Earth's would probably be detectable at an aphrodiocentric distance of ~15,000 km. If the dipole moment is really that small, the magnetic measurements would have to be performed at about one-half the above distance to have a good chance of being representative of the intrinsic field. Penetration distances even closer would enhance the chances of detecting the planetary field, or alternatively, would serve to lower the bound on the planetary magnetic moment. If a trajectory is favored that has a closest-approach distance much in excess of 15,000 km, the most interesting field measurements would likely result if the spacecraft passed through the magnetic tail region, into or close to the planet's optical shadow.

The selection of a magnetometer to carry out the above objectives should be relatively simple now that so much is known of the interplanetary medium and a bound has been established for the magnetic moment of Venus. Either a fluxgate or vector helium magnetometer would be adequate, especially if one takes into account the developments which are likely within the next 5 yr. Conservative estimates of the maximum weight and power required are 5 lb and 4 w, respectively. The major problem area would undoubtedly continue to be contamination of the measurements by spacecraft magnetic fields.

4. Solar Plasma Experiment

The ideal instrument for making solar plasma measurements in the vicinity of and en route to Venus would be similar to the OGO-E plasma probe, which incorporates both a spectrometer (electrostatic analyzer) for making detailed energy measurements and a Faraday cup probe for making flux and direction measurements. A revised design of this instrument has been proposed for *Voyager*. It weighs 15 lb, consumes 10 w if operated continuously, and occupies about 1.5 ft^3. It is capable of providing much better energy resolution, time resolution, and separation of hydrogen and helium solar-wind components than any plasma probe that has yet been flown. To use such an instrument at its maximum effectiveness requires a data rate of 10 to 50 bits/sec, since plasma data are most interesting when the plasma properties are changing rapidly, and such events cannot be predicted.

Plasma measurements at data rates that are lower by an order of magnitude would still be valuable, however. If weight and power are at a premium, a less versatile instrument could be supplied that would require about half the weight, power, and volume of the proposed *Voyager* instrument.

5. Trapped Radiation Experiment

It is well known that the *Mariner II* trapped radiation experiment produced a negative result. For this reason, any trapped radiation experiment would require either that the spacecraft pass much closer to Venus than did *Mariner II*, or penetrate the region when the Sun-planet-probe angle is greater than 140 deg.

The general scientific purposes of the experiment would be to:

1. Search for magnetically trapped particles in the vicinity of Venus and, if found, make preliminary determination of their distribution in space, their energy spectra, and their identities.
2. Monitor the occurrence of solar cosmic rays and energetic electrons in interplanetary space and study their angular distribution, energy spectra, and time histories.

The scientific problems concerning which data of interest could be obtained are:

1. Magnitude and orientation of the magnetic moment of Venus.
2. Radial extent of the atmosphere of Venus.
3. Delineation of the possibilities for aurorae and magnetic storms on Venus.
4. Interaction of the solar plasma with the magnetosphere, if any, of Venus.
5. Relationship between solar phenomena and emission of energetic particles.
6. Propagation of charged particles in interplanetary space.
7. Relationship of the occurrence of energetic particles in interplanetary space to solar and geophysical effects.

Instrumentation similar to that carried on *Mariner IV* would be quite satisfactory for these purposes. The characteristics of these detectors are shown in Table 2.

Table 2. Characteristics of trapped radiation detectors

Detector	Charged particles detected	Remarks
213 GM counter 1	Protons >500 Kev +Electrons >40 Kev	Identical detectors are oriented in different directions to get directional information
213 GM counter 2	Protons >500 Kev +Electrons >40 Kev	
213 GM counter 3	Protons >900 Kev +Electrons >70 Kev	
pn junction		
lower discriminator	Protons 500 Kev >E ≤8 Mev No electron sensitivity	
upper discriminator	Protons 900 Kev ≤E ≤5.5 Mev No electron sensitivity	

Total weight = 2.6 lb
Total power = 0.6 w
Total volume = 80 in.^{3}
Total bit rate = 1 bit/sec

6. Cosmic Dust

This would likely be the same experiment as that flown on *Mariner IV* to measure the flux of cosmic dust particles as a function of direction, distance from the Sun, and their momentum with respect to the spacecraft.

7. RF Occultation

This also would be much the same experiment as flown on *Mariner IV*. It would measure changes in the spacecraft S-band radio signal resulting from the effect of the Cytherean atmosphere during occultation. Additional signal frequencies would enhance the scientific usefulness of this experiment.

8. Ionization Chamber/Particle Flux Detector

This experiment, the same as flown on *Mariner IV*, would measure the total ionizing radiation and provide semiquantitative information about the energy and particle types composing the radiation in interplanetary space.

9. Ultraviolet Spectroscopy[2]

The ultraviolet spectrum of a planetary atmosphere is produced by charged-particle bombardment and solar radiation; this spectrum is characteristic of the atoms and molecules that make up the atmosphere and of the physical processes that excite them. The ultraviolet emission spectra from Venus results from (1) the dayglow—which is caused by solar ultraviolet radiation on the atmosphere, and (2) during periods of maximum solar activity or if trapped radiation is present, the aurora—which is caused by charged-particle bombardment of atmospheric constituents. The spectrum of the ultraviolet dayglow is the result of molecular scattering, absorption, resonance re-radiation, and fluorescence of the incident solar radiation. Thus, the composition of the upper portion of the Cytherean atmosphere may be determined at least in part from an analysis of the dayglow spectra, while the ultraviolet aurora spectra, if present, can be used to identify many of the atoms and molecules that are present. Table 3 presents a summary of the spectral emissions from both the dayglow and aurora for Venus.

Table 3. Atoms and molecules that may be detected in the Cytherean atmosphere by ultraviolet spectroscopy[3]

Phenomena	Venus
Dayglow	
Resonance re-radiation	H — 1216 A
	O — 1300 A
Fluorescence	CO — 4th Positive 1100–2600 A
Absorption	O_3 — 2000–3000 A
Aurora	N_2 — L-B-H
	N — 1200 A
	O — 1300 A
	H — 1216 A

The experiment constraints and instrument characteristics for the ultraviolet spectrometer are as follows:

1. Desired measurements to begin approximately 10^6 km from the planet, absolute distance to be established during spacecraft design
2. Scan across planet and up to one-half diam off planet
3. To satisfy the requirement for spectral resolution, it is desired that the spacecraft pass within at least 5000 km of the surface. Any greater distance from planet would decrease resolution of this instrument and affect measurement objectives
4. Cross the terminator
5. View shall not be obstructed by spacecraft within 4 deg cone about look axis
6. Field of view shall be 2.5 deg
7. Scan no closer than 10 deg to Sun–probe line
8. Weight and power approximately 25 lb and 12 w, respectively
9. Dimensions: 8 in. × 9 in. × 24 in. long.
10. Data rate will be as high as 10^3 bits/sec in real time, or approximately 2×10^5 bits/spectrogram
11. Great care must be taken in instrument design to use a detector which will not be swamped by visible light reflected from the planet

[2]Barth, C. A. (1965) The Ultraviolet Spectroscopy of Planets, TR 32-822, Jet Propulsion Laboratory, Pasadena, California.

[3]Barth, C. A. (1963) Ultraviolet Spectroscopy of Planetary Atmospheres, TR 32-516, Jet Propulsion Laboratory, Pasadena, California.

10. Photo-Imaging Experiment

The photo-imaging experiment on the Venus mission will yield new information about the nature and structure of the Cytherean atmosphere. Meteorological information similar to that obtained by the early U.S. weather satellites, with resolution at least an order of magnitude better than Earth-based observations of Venus, will be obtained. The scientific objectives of the photo-imaging experiment are as follows:

1. Obtain photographs of the entire Cytherean disk at several phase angles with about 100 km resolution

2. Map, in pairs, appearance of planet-wide clouds in near-UV and yellow light

3. Detect and observe temporal changes in cloud cover in near-UV and yellow light

4. Construct polarization maps of the Cytherean disk at several phase angles with about 100 km resolution, in two spectral windows

5. Obtain photographs of portions of the Cytherean disk with about 10 km resolution, from terminator to limb in sequential near-UV and yellow light

6. Construct polarization maps of parts of area covered at 10 km resolution, in two spectral windows

7. Observe surface markings, or, failing this, place upper limits on size and brightness differential of any surface markings that would remain undetected

The instrumentation would consist of two bore-sighted cameras of evolved *Mariner* design, mounted on a scan platform. Tape recorders, similar in design to the *Mariner-III* type but with higher playback rates, would be utilized. The following are indicative of the type of system planned:

Camera type: advanced *Mariner III*

Weight: 30 lb, 15 on scan platform

Power consumption: 20 w

Operation: shuttered exposures at minimum of 48-sec intervals; picture readout 24-sec minimum

Volume: 12 × 6 × 10 in. on scan platform; 10^3 in.^{3} on bus

Auxiliary equipment required: data processing equipment; video storage system; mechanical platform having two deg of freedom, preferably in clock and in cone angle; Planet sensor, optional if ground commands used for pointing

Data rate: 10^3 bits/sec to spacecraft transmitter

Data capacity required: 10^7 bits in video storage system, used several times

11. Monostatic Radar Experiment

A distinction is made between monostatic and bistatic radar: in monostatic the transmitter and receiver are close together; in bistatic they are widely separated. The power received in any monostatic radar system depends on the inverse fourth power of the range to the target; thus, if both terminals of a radar system can be placed near the planet to be studied, reasonably modest powers and antenna sizes can be used as compared with terrestrial-based radar systems.

A practical minimum monostatic radar experiment for a Venus flyby mission was formulated from the following constraints:

1. As a consequence of the limited weight and power capabilities of the launch vehicle and spacecraft, the radar experiment is limited to 50 lb and 75 w of input power, respectively.

2. An assumption is made that a miss-distance of about 2000 km from the surface is feasible; as the miss-distance increases, the peak power, antenna-gain product must increase to compensate for the added space loss. A closer approach, of course, is desirable.

3. The choice of wavelength falls somewhere between 3 and 10 cm. The shorter wavelengths lead to lighter equipment but may not *see through* the Venusian atmosphere.

4. The data obtainable by the radar must contain significant information about the trajectory and the Venusian surface.

To minimize the weight, a radar system consisting of a fixed antenna, a single transmitter, and a receiver is considered. A minimum wavelength of 3.3 cm may be used.

An increase to about 6 cm may be required, depending upon the outcome of Earth-based measurements of the Venusian radar cross-section during 1966.

The general parameters of the radar system follow:

Wavelength	3.3 cm
Antenna	parabola 1.2 m diam
Peak power	100 kw
Pulse width	5 μ sec
Rep. rate	10–20 pulses/sec
Signal-to-noise	10 to 40 db
Input power	75 w
Weight	50 lb (including 8-lb antenna)

The types of information which would be obtainable include:

1. Gross profile (averaged over a spot radius of 20 km)
2. Range to the planetary surface (data rate 200 bits/sec for 30 min)
3. Variations in radar cross section with look-angle
4. Pulse-to-pulse fluctuations (data rate 80 bits/sec for 30 min)

The surface parameters calculated from the last two measurements are the surface roughness to a scale of 1 to 30 cm, and a better determination of the radar reflectivity. These calculations can be made without assumptions. Values for permittivity and surface layer density can be made with assumptions as to surface layer mineral content or other measurements of this factor.

C. *Flyby Mission Plus Venus Capsule*

The capsule or drop sonde can be instrumented to provide first-hand information on some of the environmental properties of the Cytherean atmosphere. A sonde of this type, although not designed to survive the ballistic impact on the planet's surface, should carry some kind of accelerometer to distinguish between solid and liquid surfaces. It is also desirable to include a method for determining the environmental measurements as a function of altitude. Instruments to accomplish this could vary from a lightweight and simple three-axis accelerometer technique, where the capsule altitude would be interpretive as a function of the deceleration curve, to techniques using radar for precision capsule-altitude measurements.

If additional weight, power, and data capabilities are available, then it would also be desirable to incorporate an atmospheric aerosols detector, or disdrometer. An instrument commercially available through Bausch and Lomb, used for counting dust particles ranging in size from 0.3 to 10μ at concentrations between 10^3 and 10^6 particles/ft^3, may be suitably modified for this use.

A suggested capsule scientific payload is shown in Table A-3 and discussed in the following paragraphs. It should consist of a thermodynamic variables package, which includes experiments to examine the density, temperature, pressure, and velocity of sound of the atmosphere; an atmospheric composition experiment; an impact accelerometer; a visual or UV photometer to determine the cloud-layers and the scattering properties of the atmosphere, and a triaxial accelerometer. The total science payload weight is only about 16 lb.

In considering these capsule instruments, note that:

1. In no case has the weight of the ducts or tubing been taken into consideration (assumed to be structure weight).
2. It is desired that the capsule reach a velocity of Mach I as high above the planet's surface as possible, as the experiments were chosen for the subsonic regime of the descent.
3. Attitude stabilization of the capsule is required.
4. The heat shield will be a source of error during the measurements due to the thermal energy it will have at the time, and due to unpredictable aerodynamic behavior subsequent to the loss of the ablative material. The shield should, therefore, be jettisoned or its effects on the instruments clearly understood.
5. Cytherean environmental constraints that may be important for capsule and capsule instrument design are given in Appendix A.

1. Thermodynamic Variables

Four instruments are suggested for the thermodynamic variables package. These are: pressure, density, temperature, and velocity of sound. Each should have an analog output. Sterilization, if required, does not appear to be a problem with these instruments. It should be realized that a variety of instrumental techniques are possible for these experiments and the following is only one suggested approach. Capsule directional stability and a speed of less than Mach I are required for most of these instruments. The triaxial accelerometer, discussed later in this document, will provide information towards a better understanding and interpretation of these experiments; also, the aerodynamic properties of the capsule as recorded in flight by the triaxial accelerometer will provide basic information about the atmospheric density-pressure-temperature during both the supersonic and subsonic portions of the flight. Thus, the atmospheric density should be interpretive as a function of capsule oscillation and velocity for the complete deceleration profile.

*a. **Density.*** The suggested instrument would use an absorption technique in which the energy loss between a Beta source and a detector would be measured over a known gas path. The Beta source should be of low intensity to avoid affecting the cruise science radiation experiments and adequately shielded. A one millicurie source seems reasonable. The instrument is expected to perform over a pressure range from 0.1 to 100 atm with a sensitivity of approximately 2×10^{-5} g/cm^3. The instrument will weigh less than 15 oz and have a data rate of 10 bits per sample with sample interval every 500 m. A physical location adjacent to the capsule wall is desirable.

*b. **Temperature.*** A vortex tube or similar device to counteract the effect of speed on the temperature reading may be required. The device must be deployed in free stream or located at a static pressure point at the rear of the capsule and thus calibrated as a part of the total capsule system. A resistance type thermometer, or other temperature sensor, with a dynamic range from 100° to 800°K is required. This experiment would weigh about 10 oz.

*c. **Pressure.*** It is desirable to begin the pressure readings at as great an altitude as possible above the planetary surface and these data should continue in a continuous profile to the surface. A sample interval of every 500 m would be satisfactory. The accuracy of the pressure reading should be about 2% of the ambient pressure with a response time of 0.5 sec. The instrument sensors will require a static pressure point and calibration as a part of the total capsule system. The proposed instrument package would consist of two sensors—an aneroid barometer for measuring the low pressures at the higher portions of the Cytherean atmosphere and a Statham-type gauge for measuring the higher pressures that might prevail near the bottom of the atmosphere. The instrument package will weigh about 12 oz and measure 4 in. in diam by 3 in. long. The data rate will be 15 bits per sample with sample interval every 500 m.

*d. **Velocity of Sound.*** The velocity of sound in the Cytherean atmosphere will be a function of both the density and temperature of the atmospheric medium, and to a lesser extent the wind velocity; therefore, this experiment is expected to provide information that will be useful in the interpretation of the density and temperature experiments discussed above. It would really be desirable to conduct this experiment after the fashion of a so-called *grenade experiment* where the capsule would eject small charges at specified points in its traverse through the atmosphere, and the acoustical properties of the atmospheric medium between the individual point sources and the detector or geophone on the capsule could be determined. The weight, power and instrument sophistication for this type of experimental approach will not likely be possible on this mission, however. A simple lightweight practical experiment for determining the acoustical properties of the Cytherean atmosphere could be composed from two acoustic detectors separated orthogonally from a point sound source. The detector-source spread should be at least 5 cm, and physically located where least affected by the airflow about the capsule. A short boom position would be best. If this is practical then the experiment may even give some information on the atmospheric wind velocity.

A minimum experiment is listed in Table A-3. It would consist of an acoustic source and one detector to be separated by a distance of 5 cm. Only the time of travel between the source and detector would be measured; thus, the data rate would be low, say on the order of 10 bits per sample. The experiment would weigh about 10 oz, not including the boom or pickup point.

2. Atmospheric Composition

Atmospheric composition can be determined by either a mass spectrometer, gas chromatograph, or a series of simple composition instruments. The elements and compounds of major interest are: H_2O, O_2, A, N_2, CO_2, hydrocarbons, and O_3.

In the case of O_2, A, the hydrocarbons, and O_3, it would be desirable to know the percentage or amount present to a few parts per million. For CO_2 and N_2, a 1% accuracy is sufficient.

A 60° magnetic sector mass spectrometer could be considered for this experiment. This instrument is presently in breadboard stage and it uses a permanent magnet weighing about 2 lb. It has a dynamic range of 10^5, which would allow 0.01% components to be measured if one assumes a factor of ten padding in the Venus atmospheric pressure estimate. Gaseous constituents will be detectable within the mass range at 12 to 50. A few of these are: CH_4, H_2O, Ne, N_2, O_2, Ar, and CO_2.

All of these constituents can be determined in the present system down to 0.1% by volume. The present input pressure sampling limit of the system without special purging is 0.5 atm or less; however, a Bernoulli tube principle to exchange the sample in the examining chamber would be simple and weigh less than 1 lb. The mass spectrometer with the present all-solid-state electrometer can maintain its dynamic range with a 60-sec scan between masses 12 and 50. If the dynamic range were reduced to 10^4, a single scan could be made in 2 sec.

The number of data bits required by this experiment is difficult to assess without specific telemetry ground rules. Complete analog spectra would require 2500 bits. Utilizing peak detector methods, one could determine the absolute partial pressures of the three major components for less than 100 bits. The data requirements of the mass spectrometer depend entirely upon the sophistication of the scientific data required. Many tradeoffs occur between this lower limit of 100 bits and the upper limit of 2500 bits per sample.

3. Visual and/or UV Photometer

The purpose of this experiment is to determine the altitude of the cloud tops and look for a layered structure in the Cytherean atmosphere that would indicate separate cloud decks. This information will be interesting in terms of the experiments discussed above.

This instrument will weigh about 2 lb, have a data rate of less than 10 bits per sample, a look direction back along the trajectory, and it should begin to operate before Mach I or at a pressure of approximately 10 mb. It should have a sensitivity to most of the visible spectrum—say, 4000 Å to 6000 Å. If additional weight, power, and data rate are available, it would be desirable to include a narrow band sensor tuned for about 3000 Å to examine the scattering properties of the atmosphere.

4. Impact Accelerometer

A device to indicate the hardness/density of the Cytherean surface from the ballistic impact of the capsule is very desirable. Instrumentation to perform this measurement is limited by capsule weight, power, data rate, and finally, by destruction upon impact.

The suggested experiment is an impact accelerometer designed to provide an order-of-magnitude measurement of the hardness/density of the surface into which it impacts by indicating the rate of change of velocity measured between the discharge of one electrode in the outer skin of the capsule and a second electrode in the inner skin of the capsule. The capsule would be acting as a hollow shell-type accelerometer.

At impact, the outer electrode begins to collapse or flatten out. The inner electrode, not physically connected to the outer shell, feels no forces, hence continues forward with its velocity unchanged. If the target surface is completely unyielding, as is nearly the case with solid rock, the outside capsule surface will flatten on the impact surface, and the original distance between the two electrodes will close at the impact velocity. If, on the other hand, the impact surface is of very low density, or yielding, such as water, the flattening of the outer surface and the time between pulses from the discharges of each electrode will be longer. The entire capsule would be destroyed upon impact, or a few μsec after the impact accelerometer had passed its two pulses to the capsule transmitter.

5. Three-Axis Accelerometer

This instrument will be an integral part of the complete capsule system. It is expected to provide:

1. The primary science data for the supersonic portion of the capsule flight, and

2. Information that will be useful in the interpretation of the other capsule instruments.

For the supersonic portion of the flight, known aerodynamic properties of the capsule will cause it to react to the Cytherean atmosphere by deceleration and oscillation thus providing information interpretive in terms of atmospheric density-pressure-temperature. For the subsonic portion of the flight, and down to the terminal velocity point, the 3-axis accelerometer will provide information interpretive in terms of atmospheric density-pressure-temperature, and also, relative altitude information that will be useful for interpreting the data from the other capsule science instruments.

During the supersonic entry portion of the capsule descent, an ionization sheath will likely form to interfere with communications; therefore, data storage capabilities will be required to preserve these data for later transmission. The data rate for the 3-axis accelerometer will be less than 40 bits per sample and the sample interval during the high speed portion of the flight should be every second if possible to a total recorder capacity of 5000 bits or 2 min. The total duration of the supersonic portion of the flight will be a function of entry velocity, entry angle, atmospheric density, capsule shape, capsule density, and other considerations, and therefore is unknown at this time. If the supersonic portion of the flight is expected to last for longer than the data storage capabilities of the recorder, then a 2-sec sample interval is recommended or data logic must be used to control the sampling rate.

During the subsonic portion of the descent, the 3-axis accelerometer should be sampled every 500 m or as frequently as the data link will allow. This experiment including the data recorder will weigh approximately 3 lb.

APPENDIX A

Cytherean Environmental Constraints

Table A-1. Selected planetary data for Venus

Mass:	4.86954×10^{27} grams	(*Mariner II* value, 1962)
	4.85×10^{27} grams	(from Rabe by perturbations of asteroid Eros, 1950)
Diameter:	12,198 km	(0.955 spherical Earth diam) (Menzel and de Vaucouleur, from occultation of Regulus, 1961; depth of atmosphere estimated at 49 km)
	12,590 km (0.988 Earth)	(Rabe, 1929)
	12,400 km (0.973 Earth)	(Russell, Dugan, and Stewart, 1945)
Density:	4.99 ± 0.15	(Rabe, 1950)
	4.9	(Russell, Dugan, and Stewart, 1945)
	4.86	(Whipple, 1941)
	5.03 ± 0.12	(Jeffreys, 1937)
	5.06	(Urey, 1957)
	5.21	(Smart, 1951)
Surface gravity:	around 0.86 Earth gravity	
Oblateness:	unknown	
Rotation period and axis orientation:	$-250 \text{ days} \begin{smallmatrix} +7 \\ -4 \end{smallmatrix} \text{ days}$ with spin axis pointing toward	
	$\alpha = 255^\circ \begin{smallmatrix} +10^\circ \\ -\ 4^\circ \end{smallmatrix}$, $\delta = +68^\circ \pm 4^\circ$ (Carpenter, 1964)	
Orbital eccentricity:	0.007	
Inclination of orbit:	3° 24′	
Distance to Earth at IC:	42×10^6 km	
Distance at SC:	257×10^6 km	
Sidereal period of revolution:	225 days	
Mean distance to Sun:	108×10^6 km	

Table A-2. Typical flyby experiments

Instrument	Weight, lb	Power, w	Remarks
1a. Microwave spectrometer (atmospheric sensor)	35	30	Obtain the limb-to-limb brightness temperature at several wavelengths from 3 mm to 3 cm. From these data, one would hope to get information about the composition, the three-dimensional physical and thermal structure, the circulation, the density, etc., of the atmosphere.
1b. Microwave imager (surface imager)	25	10	Obtain a thermal map of a traverse of the Venusian surface at a wavelength longer than 3 cm. From these data, one would hope to get information on planetary geomorphology, thermal abnormalities, and an estimate of surface composition and structure.
1c. Microwave spectrometer (combined atmospheric sensor and surface imager)	50	40	Same as 1a and 1b.
2. Infrared experiment	35	20	Michelson interferometer technique at 1.2 to 5 microns with a spectral resolution of 0.5 cm^{-1} for information about atmospheric composition, vertical temperature and nature and height of clouds.
3. Magnetometer	5	5	To investigate planetary and interplanetary magnetic fields, their relationship, characteristics, magnitude, direction, and orientation.
4. Solar plasma experiment	15	10	Similar to OGO-E plasma experiment for making detailed energy measurements, as well as flux and directional measurements.
5. Trapped radiation detectors	2.6	0.7	Planetary: To search for magnetically trapped charged particles in vicinity of Venus. If present to study intensity, directional and spatial distribution; also interplanetary cosmic rays.
6. Cosmic dust	2.5	0.2	Interplanetary: To measure flux of cosmic dust particles as function of direction, distance from Sun, and momentum with respect to spacecraft.
7. R.F. occultation			Planetary: Measure changes in S/C radio signal resulting from effect of Venus atmosphere during occultation.
8. Particle flux/ion chamber	2.5	0.35	*Particle Flux*, interplanetary: Used in conjunction with ion chamber to monitor energetic particle and photon radiation in interplanetary space. Provides semiquantitative data about energy and particle types composing the radiation. *Ion Chamber*, interplanetary: To measure total ionizing radiation (cosmic rays and/or particles) and variation with time and position in the solar system.
9. Photo-imaging experiment	15	20	Would provide information about nature and structure of Cytherean atmosphere similar to data from early U.S. satellites for Earth.
10. Ultraviolet spectroscopy	25	12	Determination of abundance and height distributions of principal atmospheric constituents obtained from UV spectra of day, night, and twilight portions of Venus, with emphasis on lighted side.
11. Radar experiment	50	75	Would provide information on surface profile or topography, range to planetary surface, small scale surface roughness (1 to 30 cm), and reflectivity and electrical properties of planetary surface.

Table A-3. Typical Venus capsule instruments

Instrument	Measurement capabilities	Approx weight	Approx power	Bits/sample & total information (Venus)
Aerometeorometer	Static temperature: 180 to 800°K, accuracy of measurement is ±1% of ambient temperature.	10 oz	70 mw	9 bits/sample—measure every 500 m
	Static pressure: 10 mb to 100 atm. The accuracy of measurement is approximately 2%.	10 oz	100 mw	15 bits/sample—measure every 500 m
	Density: 2×10^{-4} to 30 kg/m^3, accuracy of measurement is ±1% of ambient.	15 oz	250 mw	10 bits/sample—measure every 500 m
	Velocity of sound: 250 to 380 m/sec is 1% of ambient (accuracy of measurement).	10 oz	300 mw	10 bits/sample—measure every 500 m
Mass spectrometer	Determines the composition of the atmosphere in the mass range of 12 to 50 amu.	5 lb	6 w	1100 bits/sample, 5500 bits total. This is for complete analog spectra. Bit rate can be reduced to 100 bits/sample
Visual or UV photometer	Determines the cloud tops and cloud base and the optical properties of the Cytherean atmosphere.	2 lb	1.0 w	7 bits/sample—measure every 5 sec
Impactometer	Distinguishes between a hard and a soft surface; e.g., unconsolidated sand-like material and any consolidated surface.	3 lb	1.0 w	2 μsec pulses on the capsule carrier frequency
Three-axis accelerometer	Provides data for determining pressure-density-RT product as a function of altitude.	3 lb (includes 5000-bit storage unit)	1.0 w	40 bits/sample—sample every second during supersonic flight and every 500 m during subsonic flight

APPENDIX B

Engineering Model for the Atmosphere of Venus

Venus experts do not agree on a model for the detailed structure or even the gross structure for the planet's atmosphere. There are differing opinions on whether the surface temperature is high or moderate, on whether the surface pressure is high or moderate, on whether water is present or not, on whether the clouds are ice or not, etc. All this has been stated earlier, but it should be emphasized. Thus, if there is to be any reasonable hope for the success of the type of mission discussed here, the atmospheric entry capsule must be designed to survive an extremely wide range of atmospheric conditions.

The 8-to-14-μ brightness temperature is 234°K, and it is generally agreed that this value must refer to a level somewhere near the cloud tops. There is not total agreement that the 3 cm brightness temperature is entirely a surface contribution; however, assuming this to be the case for capsule design, the ground temperature at the subsolar point may rise as high as 800°K. This gives a gradient of 566°K between clouds and ground.

The atmosphere is known to contain CO_2, but most scientists feel this is a minor constituent ($<$ 10%), although again agreement is not unanimous. Assuming an atmosphere of 90% N_2, 9% CO_2, and 1% A, the mean molecular weight is 29.6, the dry adiabatic lapse rate is $\Gamma = -8.5°K/km$, and the mean ratio of specific heats is $\bar{\gamma} = 1.39$.

It is not likely that the lapse rate is super-adiabatic. If it is adiabatic then the atmosphere should have a thickness of about 67 km from cloud tops to surface. If the lapse rate is sub-adiabatic then the atmosphere could be somewhat thicker.

In an adiabatic atmosphere, pressure differences between two levels are given by

$$\frac{P_1}{P_2} = \left(\frac{T_1}{T_2}\right)^{\frac{\gamma}{\gamma - 1}}$$

For the atmosphere being considered, the pressure ratio $P_1/P_2 = 73.9$. If the cloud top pressure is ½ atm, a reasonable value according to some ideas, the surface pressure will then be 37 atm. (In fact, it would actually be some 40 atm due to the fact the gases could then no longer be treated as ideal.) Some atmospheric models have had cloud top pressures as low as 20 mb, resulting in surface pressures of less than one atmosphere, although these seem *very* unlikely.

It seems probable that the surface pressure on Venus is between 5 and 50 atm, but at the present time pressures as low as 1 atm or as high as 200 atm cannot be ruled out with any certainty. Indeed the setting of this one question, the surface pressure, would be perhaps the single most important contribution that could be made to our knowledge of Venus, as it would immediately discard at least two thirds of our present conflicting ideas about the planet.

REFERENCES

1. Adams, W., Sr., and Dunham, T., Jr., *Publications of the Astronomical Society of the Pacific*, Vol. 44, 1932, pp. 243–245.
2. Carpenter, R. L., "Study of Venus by CW Radar: Results of the 1964 Conjunction," *The Astronomical Journal*, Vol. 70, 1965, p. 134 (A).
3. Carpenter, R. L., "Study of Venus by CW Radar: 1964 Results," *The Astronomical Journal* (in press 1966).
4. Chamberlain, J. W., "The Atmosphere of Venus Near Her Cloud Tops," *The Astrophysical Journal*, Vol. 141, 1965, p. 1184.
5. Kuiper, G. P., "Infrared Spectra of Stars and Planets, Photometry of the Infrared Spectrum of Venus, 1–2.5 Microns," *Communications of the Lunar & Planetary Laboratory*, Vol. 1, No. 15, 1962, p. 83.
6. Sinton, W. M., "Infrared Spectroscopy of Planets and Stars," *Applied Optics*, Vol. 1, 1962, p. 105.
7. Moroz, V. I., *New Observations of the Infrared Spectrum of Venus, λ1.2–3.8 Microns*, Shternberg Institute, Russia, 1963.

REFERENCES (Cont'd)

8. Kellogg, W. W., and Sagan, C., "Venus," *The Atmospheres of Mars and Venus*, National Academy of Science–National Research Council, Washington, D.C., 1961, Chapter IV.

9. Dollfus, A., "Observation de la vapour d'eau sur la planète Venus," *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, Vol. 256, 1963, p. 3250.

10. Bottema, M., Plummer, W., and Strong, J., "A Quantitative Measurement of Water-Vapor in the Atmosphere of Venus," *Annales d'Astrophysique*, Vol. 28, 1965, p. 225.

11. Spinrad, H., "A Search for Water Vapor and Trace Constituents in the Venus Atmosphere," *Icarus*, Vol. 1, 1962, p. 266.

12. Prokofyev, V. K., and Petrova, N. N., "On the Presence of Oxygen in the Atmosphere of Venus," *Izvestiya Krymskoi Astrofizicheskoi Observatorii*, Vol. 29, 1963, p. 3. *JPL Astronautical Information Translation No. 33.*

13. Prokofyev, V. K., "On the Presence of Oxygen in the Atmosphere of Venus," *Izvestiya Krymskoi Astrofizicheskoi Observatorii*, Vol. 31, 1964, p. 276.

14. Spinrad, H., and Richardson, E. H., "An Upper Limit to the Molecular Oxygen Content of the Venus Atmosphere," *The Astrophysical Journal*, Vol. 141, 1965, p. 282.

15. Kozyrev, N. A., *Izvestiya Krymskoi Astrofizicheskoi Observatorii*, Vol. 12, 1954, p. 169.

16. Newkirk, G., Jr., "The Airglow of Venus," *Planetary and Space Science*, Vol. 1, 1959, p. 32.

17. Weinberg, J. L., and Newkirk, G., Jr., "Airglow of Venus: a Reexamination," *Planetary and Space Science*, Vol. 5, 1961, p. 163.

18. Kaplan, L. D., "A New Interpretation of the Structure and CO_2 Content of the Venus Atmospheres," *Planetary Space Science*, Vol. 8, 1961, p. 23.

19. Spinrad, H., "Spectroscopic Temperature and Pressure Measurements in the Venus Atmosphere," *Publications of the Astronomical Society of the Pacific*, Vol. 74, 1962, p. 187.

20. Pollack, J. B., and Sagan, C., "The Microwave Phase Effect of Venus," *Icarus*, Vol. 4, 1965, p. 62.

21. Barath, F. T., et al., "Mariner II: Preliminary Reports on Measurements of Venus, Microwave Radiometers," *Science*, Vol. 139, 1963, p. 908.

22. Barath, F. T., et al., "Mariner II Microwave Radiometer Experiment and Results," *The Astronomical Journal*, Vol. 69, 1964, p. 49.

23. Clark, B. G., and Kuz'min, A. D., "The Measurement of the Polarization and Brightness Distribution of Venus at 10.6-cm Wavelength," *The Astrophysical Journal*, Vol. 142, 1965, p. 23.

24. Sinton, W. M., and Strong, J., "Radiometric Observations of Venus," *The Astrophysical Journal*, Vol. 131, 1960, p. 470.

25. Sagan, C., and Pollack, J. B., "Spacecraft Observation of Venus Infra-Red Limb-Darkening," *Annales d'Astrophisique*, Vol. 28, 1965, p. 229.

REFERENCES (Cont'd)

26. Pollack, J. B., and Sagan, C., "The Infrared Limb-Darkening of Venus," *Journal of Geophysical Research,* Vol. 70, 1965, p. 4403.

27. Urey, H. C., *The Planets, Their Origin and Development,* Yale University Press, New Haven, Connecticut, 1952.

28. Lyttleton, R. A., *On the Internal Constitution of the Terrestrial Planets,* TR 32-522, Jet Propulsion Laboratory, Pasadena, California, 1963.

29. MacDonald, G. J. F., "On the Internal Constitution of the Inner Planets," *Journal of Geophysical Research,* Vol. 67, 1962.